QUARTERLY REPORT – PUBLIC PAGE

Guidelines for the Identification of Stress Corrosion Cracking Sites and the Estimation of Re-Inspection Intervals for Stress Corrosion Cracking Direct Assessment

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Technical Status

Progress was made on a number of the scheduled tasks during the quarter ending February 28, 2009. Progress has been made on the collection of field data from operating pipeline companies (Task 1), the analysis of the literature R&D data and its validation against the field data (Task 2), and Technology Transfer (Task 4).

Efforts have continued to collect field data from operating pipeline companies. However data collection has been affected by the limited resources available within the companies contacted to support the effort. The review and analysis of the literature R&D studies is continuing. A more statistical approach is being applied to the validation process in order to provide as quantitative an analysis as possible. In addition, a slightly different approach is being used for validation of the R&D guidelines. Instead of first developing the guidelines and then looking for field data against which to validate them, the field data themselves are being interpreted in terms of the R&D information and guidelines then developed which have implicitly been validated against the field information. In terms of Technology Transfer, detailed discussions and a Technical Review meeting were held with DOT PHMSA representatives this quarter including a meeting at PHMSA's offices in Denver, CO on January 29, 2009. Copies of the slide presentations are attached to this quarterly report. In addition, various activities associated with a presentation on the project at NACE CORROSION/2009 were completed.

Limited progress was made on Task 3: Documentation, and there is no detailed reporting for that task presented in this report.

Task 1: Data Collection

Sub-task 1.1 Data Collection from Literature

As noted in earlier quarterly reports, the formal collection of information from the R&D literature has been completed. However, as part of the project activities, a monthly review of techinical literature and references is carried out in order to capture new publications that are relevant to the study. The number of such publications varies from month to month, but is of the order of 3-4 per month.

Sub-task 1.2 Data Collection from Pipeline Operators

Collection of field data from operating pipeline companies is being coordinated as part of a larger PRCI-led effort. The aim of the effort is to develop an extensive database of SCC findings by PRCI companies and, where possible, by non-member organizations. To this end, a project team has been assembled comprising Mark Piazza (PRCI), Fraser King (Integrity Corrosion Consulting Ltd), Raymond Fessler (Biztek Consulting), and Jenny Been (Alberta Research Council). Over the past 6 months this team has been personally contacting pipeline companies to secure SCC data for this and other PRCI-funded studies. The nature of the data being requested has been described in earlier quarterly reports.

To date, data has been obtained from 6 companies (three full data sets and three partial sets) and 12 companies have promised data but have yet to provide it. Only one of the 37 companies contacted has refused to supply data. In addition, there are a number of other sources of data that are useful for the current study, including: a recently published JIP study that is being incorporated by ASME into B31.8/8S, trending studies from CEPA, earlier compilations of data (although these only provide "rolled-up" data which may be of limited use).

Continued efforts to obtain more data are planned for the coming quarter.

Task 2: Data Analysis and Validation

Work has continued on the analysis of the literature R&D information and the development of guidelines for locating SCC and determining the rate of cracking. In the past quarter greater emphasis has been placed on statistical analysis of the field and R&D data in order to provide quantitative validation of the guidelines wherever possible. In addition, a slightly different approach to developing guidelines has been investigated during the past quarter. Instead of deriving guidelines and then validating them against field data, an attempt has been made to derive guidelines by interpreting field observations based on the R&D literature. An example of this approach will be presented later.

Depending upon the type and quantity of data available (either lab data or field observations), statistical analysis may be useful in both deriving quantitative relationships from the R&D literature and in validating them against field data.

Various statistical techniques are available for data analysis. A technique that is often employed in corrosion analyses is the statistics of extreme values or Extreme Value Analysis (EVA). EVA is the analysis of the distribution of the extreme values (the maxima or minima) of a series of observations. It is useful in corrosion science because it is generally the extreme values (e.g., the fastest corrosion rate, the threshold potential for pit initiation, etc.) that determine the lifetime of a component subject to corrosion.

The statistics of extremes, both maxima and minima, can be described by a generalized extreme value function which, expressed as a cumulative distribution, is given by

$$F(x) = \exp\left\{-\left[1 - \frac{k}{\alpha}(x - \lambda)\right]^{1/k}\right\} \tag{1}$$

where k, λ, and α are the shape, location, and scale parameters, respectively. In corrosion science, the maximum is used to predict, for example, the depth of the deepest pit or crack and the minimum can be used to predict the service life of a component. The generalized extreme value function can take one of three forms, depending upon the magnitude and sign of the shape parameter (k). The Type I function is characterized by $k = 0$, Type II by $k < 0$, and Type III by $k > 0$. For the maxima, Types I, II, and III correspond to distributions with no bound, a lower bound, and an upper bound, respectively.

The form of the generalized extreme value function used here, and that most commonly applied to corrosion applications, is the maximum Type I distribution, also known as the Gumbel distribution. The Gumbel probability density function $f_I(x)$ is given by

$$f_I(x) = \frac{1}{\alpha} \exp\left[-\frac{(x - \lambda)}{\alpha} - \exp\left(-\frac{(x - \lambda)}{\alpha} \right) \right] \qquad (2)$$

and the Gumbel cumulative distribution function $F_I(x)$ by

$$F_I(x) = \exp\left[-\exp\left(-\frac{(x - \lambda)}{\alpha} \right) \right] \qquad (3)$$

Other useful characteristic parameters of the Gumbel distribution are the mode (x_m), given by

$$x_m = \lambda \qquad (4)$$

the mean (μ), given by

$$\mu = \lambda + \gamma\alpha \qquad (5)$$

where γ is Euler's constant ($\gamma = 0.57722$), the median (δ), given by

$$\delta = \lambda - \alpha \ln(\ln 2) = \lambda + 0.3665\alpha \qquad (6)$$

the variance (V), given by

$$V = \frac{\pi^2}{6} \alpha^2 \qquad (7)$$

the standard deviation (σ), given by

$$\sigma = \frac{\pi}{\sqrt{6}} \alpha \qquad (8)$$

The cumulative distribution function $F'(x)$ for a sample of area A' is related to the cumulative distribution function $F'(x)$ for a sample of area A by

$$F'(x) = [F(x)]^{A'/A} \qquad (9)$$

The distribution $F'(x)$ is characterized by the same value of the scale parameter α, but by a different value for the location parameter, given by

$$\lambda' = \lambda + \ln(A'/A) \qquad (10)$$

Figure 1 shows plots of the Gumbel probability density and cumulative distribution functions for values of α and λ of 1. An increase in the location parameter (equivalent to the mode) shifts the distribution to the right, whereas an increase in the scale parameter (related to the standard deviation) broadens the distribution. The Gumbel distribution was used extensively by Parkins to describe the distribution of crack growth rates for both high- and near-neutral pH SCC (Parkins 2000).

As an application of EVA, consider the data in Figure 2 (Parkins 2000). This figure shows the effect of cyclic loading (as measured by the ratio of the minimum to the maximum load, the R ratio) on the threshold stress for crack initiation for eight steels in a simulated high-pH SCC environment. The range of threshold stresses (as indicated by the length of the horizontal bars) is plotted against the value of 72% of the actual yield strength of the steel, a % value corresponding to the maximum operating pressure of Class 1 pipelines in the U.S. It is apparent that as the magnitude of the pressure fluctuations increase (i.e., decreasing R value), the threshold stress for crack initiation decreases.
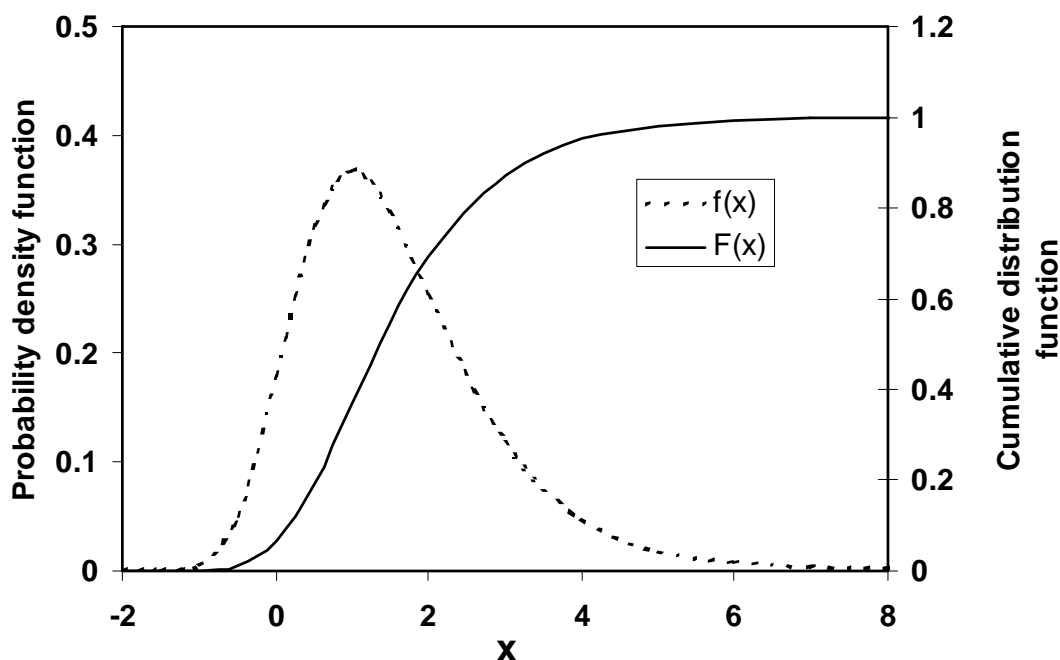
Figure 1: Examples of the Gumbel Probability Density and Cumulative Distribution Functions for Hypothetical Values for the Scale and Location Parameters ($\alpha = \lambda = 1$).
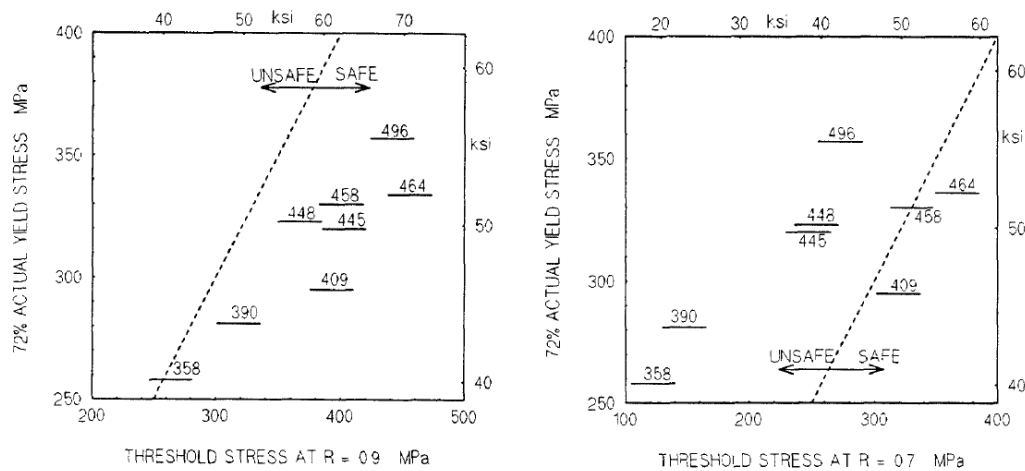
Figure 2: Dependence of the Threshold Stress for the Initiation of High-pH SCC on the Ratio of the Minimum to Maximum Stress (R Ratio) Applied During Cyclic Loading (after Parkins 2000). The numbers above the horizontal lines representing the uncertainty in the threshold stress are the actual yield stress for the pipeline steel sample.
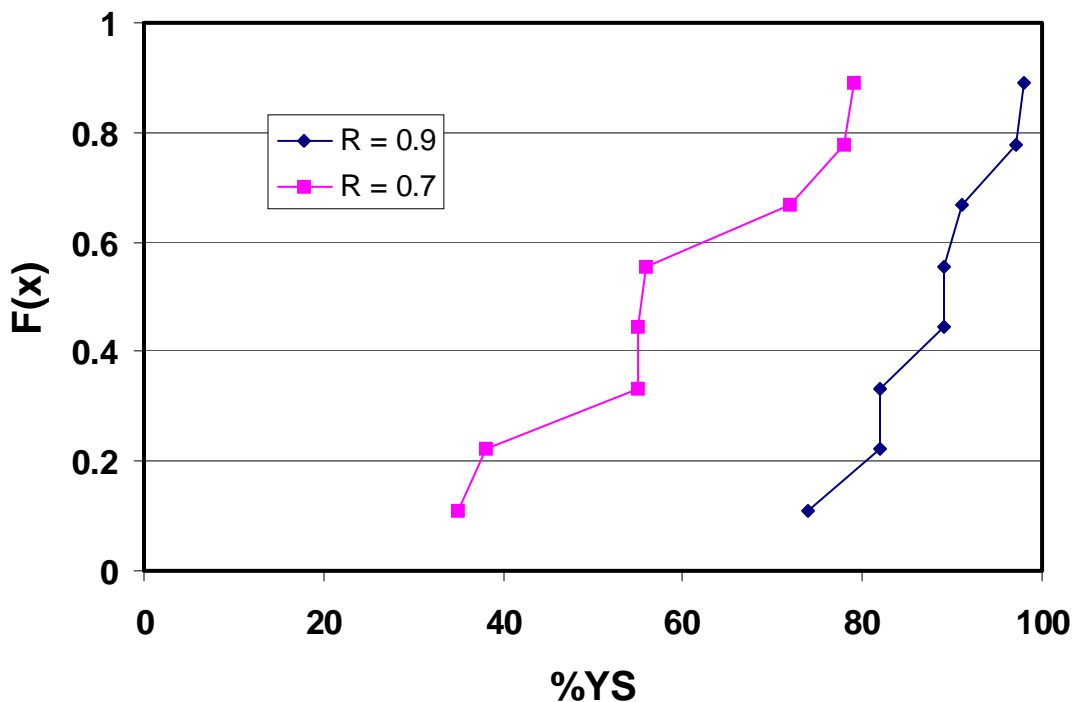

Figure 3: Cumulative Distribution Function for the Threshold Stress for High-pH SCC Crack Initiation as a Percentage of the Actual Yield Stress for Two Different Cyclic Loading Regimes Based on Laboratory Data Cited by Parkins (2000).

The data in Figure 2 can be analyzed using EVA, since they refer to the threshold stress for crack initiation. Figure 3 shows the cumulative distribution function F(x) for the two sets of data in

Figure 2, where F(x) is the probability that the threshold stress for crack initiation (expressed as a % of the actual yield stress) is less than or equal to the value x. The cumulative distributions F(x) are not smooth functions of %YS (x) because of the relatively small population (n = 8). However, these curves can be analyzed to give values for the characteristic shape and location parameters, variance and standard deviation of the extreme-value distribution (not given here).

As noted above, a different approach is being investigated for developing the SCC guidelines. Previously, guidelines were derived from the R&D literature and were then validated by comparison against field data. As described in the previous quarterly report, this approach meant that several individual guidelines had to be combined for the validation process, and the validity of individual guidelines was not possible. This approach, and its limitations, are exemplified by the example of factors that would lead to a decrease in the frequency and severity of SCC with increasing distance downstream of compressor stations. Based on the R&D literature, there are several factors relating to the dependence of high-pH SCC on stress and temperature that would lead to a dependence on distance away from the compressor. However, because there is only a single data set for validation, it is not possible to test the validity of the individual guidelines.
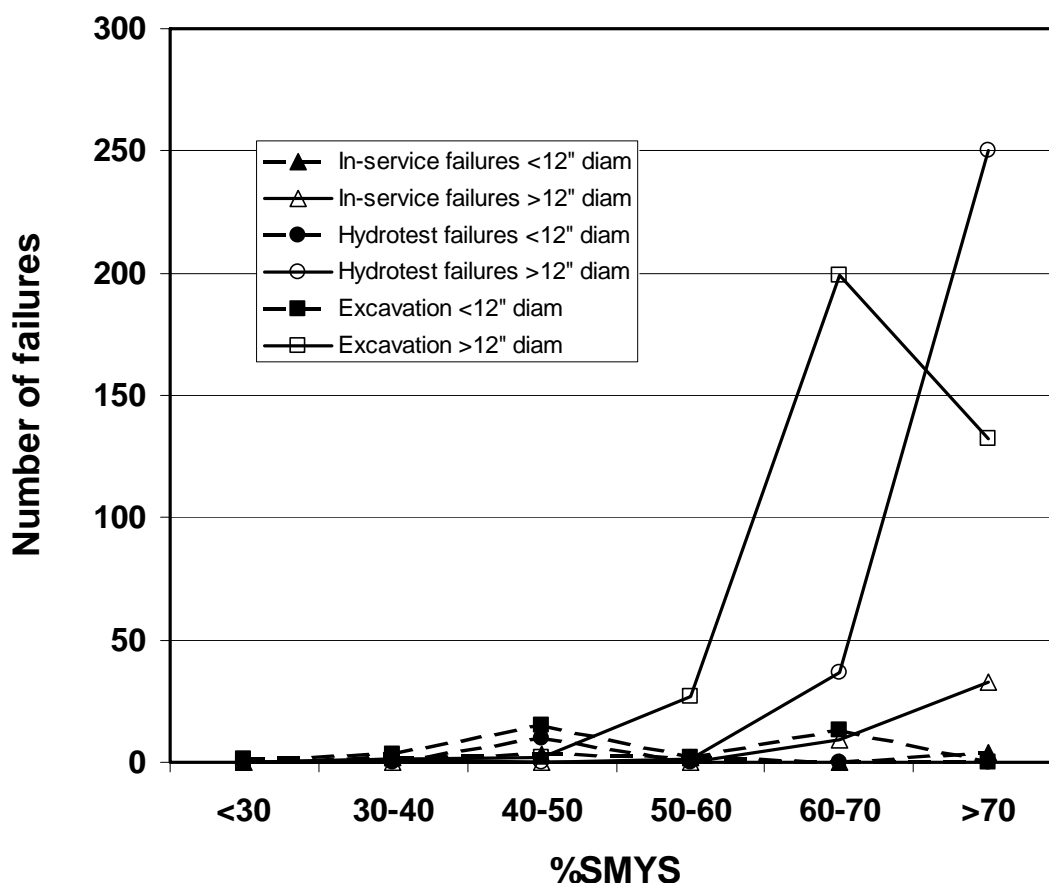

Figure 4: Effect of Operating Stress on High-pH SCC In-service and Hydrotest Failures and for Cracking Found by Excavation Classified by the Diameter of the Pipeline (Greater or Less Than 12").

Therefore, a different approach has been tested recently. In this approach, a set of field data is interpreted in terms of the mechanistic understanding developed from the laboratory R&D and the concepts or mechanisms that best describe the field observations are then, by inference, validated rules or guidelines.

For example, Figure 4 shows the dependence of the number of high-pH SCC failures (in-service and hydrotest) and incidence of cracking found by excavation as a function of the maximum operating stress (expressed as a % of the specified minimum yield stress %SMYS). The data are divided into two sets, one for pipelines with a diameter greater than 12" and another for lines with a diameter less than 12". This distinction can, to a first approximation, be taken as a distinction between smaller gathering lines and laterals and larger transmission pipelines.

Two features are immediately obvious from the data. First, a higher number of failures and incidence of high-pH SCC has been observed, or at least reported, on transmission pipelines. However, in order to draw such a conclusion, the data need to be normalized to the relative lengths of laterals and transmission lines in service, an omission that compromises the validity of the following preliminary analysis. Second, whilst SCC tends to occur on transmission lines only at higher pressures, those on gathering lines occur over a wide range of pressures.
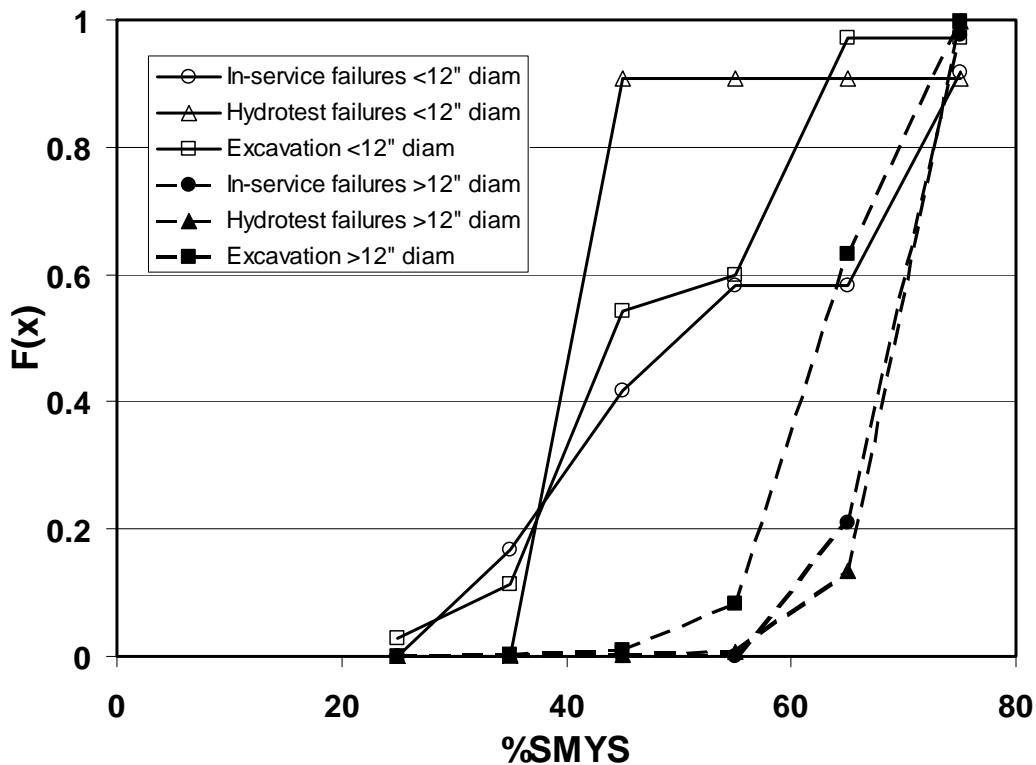

Figure 5: Cumulative Probability of High-pH SCC Failures and Reports from Excavations as a Function of %SMYS for Large and Small Diameter Pipelines.

Figure 5 shows these same field data expressed as a cumulative probability as a function of %SMYS. The distinction between the behaviour of the large and small diameter pipes is clearly seen.

It is interesting to compare this EVA distribution with that for the laboratory crack initiation data from Figure 3. Figure 6 shows the comparison for the two different R values used in the laboratory tests. Unfortunately, there is no indication from the field data of the R values for the various operating pipelines. However, typically, smaller gathering lines and laterals experience deeper pressure fluctuations (smaller R values) than large transmission pipelines (Van Boven et al. 2002).
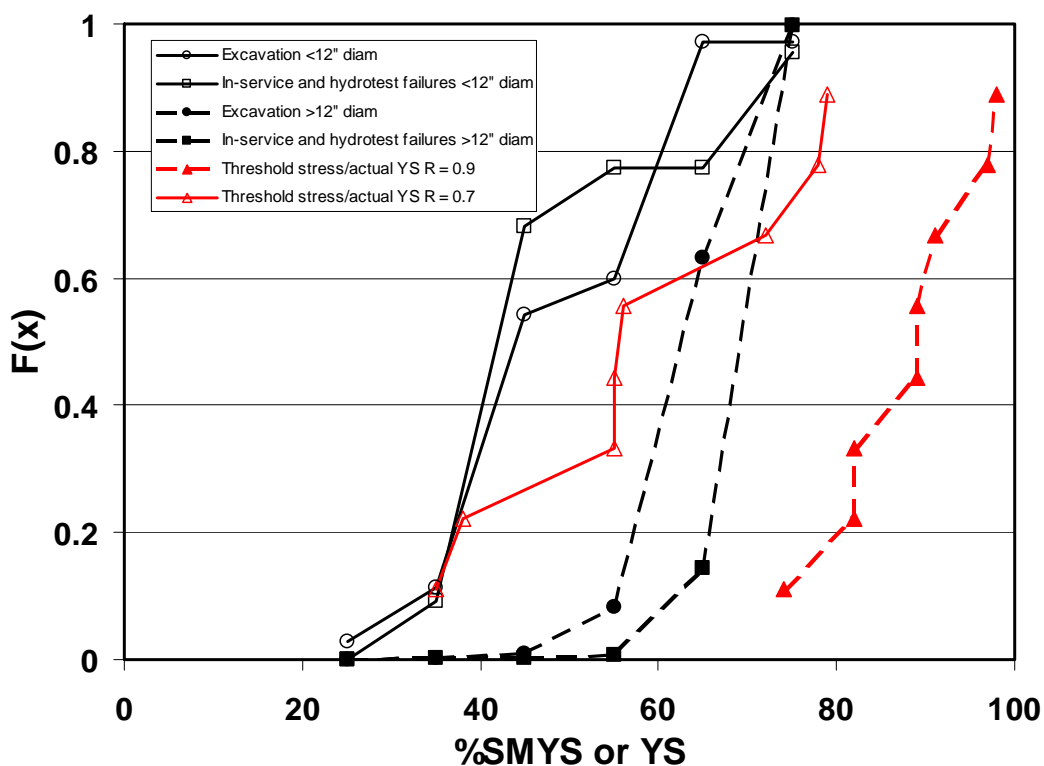

Figure 6: Comparison of Cumulative Probability Plots for Field High-pH SCC Data and Laboratory Threshold Crack Initiation Data as a Function of the Percentage of the Specified Minimum or Actual Yield Stress.

Based on this preliminary comparison of field and laboratory data, therefore, one might conclude that the lab data indicating an effect of R value on the threshold stress for high-pH crack initiation can explain the field observations of the effect of operating stress on cracking. However, much deeper analysis is required, partly because the lab data refer only to initiation, whereas the field observations are significantly influenced by the extent of crack growth.

However, the above discussion serves as an example of the alternative approach that is being tested for deriving validated rules and guidelines from the R&D literature.

References

Parkins, R.N. 2000. A review of stress corrosion cracking of high pressure gas pipelines. NACE CORROSION/2000 (NACE International, Houston, TX, 2000), paper 00363.

Van Boven, G., R. Sutherby and F. King. 2002. Characterizing pressure fluctuations on buried pipelines in terms relevant to stress corrosion cracking. In Proc. International Pipeline Conf. 2002 (ASME International, New York, NY), paper 271498, 1687-1698.

Task 3: Documentation

No specific activity during this quarter.

Task 4: Technology Transfer

A meeting was held between the project team and DOT PHMSA representatives (COTR Kimbra Davis and James Merritt) to discuss progress on the project. The slides presented at that meeting are appended to this report. Meeting minutes are also attached.

Issues, Problems or Challenges

The project is currently behind schedule and a time and cost modification request will be submitted to DOT within the next milestone period.

Plans for Future Activity

The following activities are anticipated for the next milestone period:

Technical Progress

1. The project will work on continued data analysis and development of guidelines for each module or stage of the guidelines. The focus will be on all four modules.

2. Continue to work with pipeline companies to obtain field data for validation of the rules and guidelines.

3. Documentation of the main text and supporting appendices will be emphasized in the next quarter.

4. Submit a monthly status report

5. Submit a time and cost modification request to DOT PHMSA

Tests and Demonstrations

No tests or demonstrations are planned for the next reporting period.